UNIVERSITI PUTRA MALAYSIA

PERFORMANCE OF OPTICAL LABEL SWITCHING NETWORK WITH MULTI PROTOCOL LABEL SWITCHING IMPLEMENTATION

RIZALUDIN KASPIN

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By

RIZALUDIN KASPIN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Partial Fulfillment of Requirements for the Degree of Master of Science

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DEDICATION

To all mankind

Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in partial fulfillment of the requirements for the degree of Master of Science

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October 2002

Chairman : **Associate Professor Mohamad Khazani Abdullah, Ph.D.**

Faculty : **Engineering**

Today, the phenomenal traffic growth of Internet leads to the dramatic expansion of the transmission lines in the Internet Protocol (IP) network. Fibre optics as the key of the future transmission networks has evolved to provide almost limitless information carrying capacity via its Wavelength Division Multiplexing (WDM) technology. However, the relatively sluggish development in switching technology which still operates in electronics domain might creates bottleneck in various part of the network. Thus, the concept of All-Optical Network has been introduced. Here a lot of approaches have been proposed to bring IP closer to the optics technology such as IP over WDM. On the other hand, IP technology itself has evolved from pure connectionless system to connection-oriented in order to cope with the Quality of Service (QoS) demanded by the end users. Thus, the concept of Multi Protocol Label Switching (MPLS) has been standardized to achieve this.

In this thesis, connection-oriented Optical Label Switching (OLS) network implementing MPLS system has been proposed as a viable and future proof network

architecture. However since this is a relatively new area, comprehensive studies on this subject are yet to be available. Resource contention resolutions have been fairly studied in OLS connectionless network, however the percentage of packets arriving in sequence which is an important performance parameter in connection-oriented network has been neglected. In the network layer study of this research project, optical buffering via fibre delay lines (FDL) has been demonstrated as effective in mitigating packet losses but poor in assuring in-sequence packets arrival. Reduced Length Multistage FDL buffering and wavelength conversion have been proposed and demonstrated as the viable contention resolution techniques which assure higher degree of in-sequence packets arrival.

Another important research area in OLS is on devising technique to accomplish label switching in each OLS network node. In the physical layer study of this project, Parallel Lambda technique has been introduced and demonstrated as a simple and effective way to facilitate label switching. The label at lower bit rates than the payload is generated at a few nanometer above the payload operating wavelength but within the same WDM multiplexer channel. This label travels together in parallel with the payload throughout the network and manages label switching at each node while maintaining acceptable power levels and bit error rates.

In conclusion, Optical Label Switching network implementing MPLS system can provide a better solution to the realization of future all-optical networks. Beside its potential in providing higher network throughput due to its smallest switching granularity, it also provides quality in its output by assuring high degree of in-sequence packets arrival. Finally by adopting Parallel Lambda technique in the switch architecture a simple and efficient label switching mechanism can be realized.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENCAPAIAN RANGKAIAN PENSUISAN LABEL OPTIK DENGAN PERLAKSANAAN PENSUISAN LABEL PELBAGAI PROTOKOL

Oleh

RIZALUDIN KASPIN

Oktober 2002

Pengerusi : **Profesor Madya Mohamad Khazani Abdullah, Ph.D.**

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Peningkatan yang mendadak terhadap trafik Internet pada hari ini telah menjana perkembangan yang dramatik pada talian penghantaran di dalam rangkaian Protokol Internet (IP). Gentian optik sebagai kunci kepada rangkaian penghantaran masa depan telah berubah dengan menawarkan peningkatan kapasiti pembawaan maklumatnya yang hampir tiada had melalui Teknologi Penggabungan Pembahagian Gelombangjarak (WDM). Walaubagaimanapun kelembapan yang relatif pada perkembangan teknologi pensuisan yang masih beroperasi di dalam ruanglingkup elektronik akan menyebabkan kesesakan di pelbagai tempat di dalam rangkaian. Oleh kerana itulah maka konsep Rangkaian Optik-Sepenuhnya telah diperkenalkan. Disini banyak pendekatan telah dicadangkan untuk membawa Protokol Internet lebih hampir kepada teknologi optik seperti Protokol Internet di atas Penggabungan Pembahagian Gelombangjarak. Di satu pihak yang lain, teknologi Protokol Internet itu sendiri telah berubah dari sistem tanpa-sambungan kepada sistem sambungan-terbina demi untuk menghadapi keperluan Servis Berkualiti yang diminta oleh para

pengguna. Oleh kerana itulah konsep Pensuisan Label Pelbagai Protokol (MPLS) telah dipiawaikan.

Di dalam tesis ini, rangkaian Pensuisan Label Optik dengan sambungan-terbina yang melaksanakan sistem Pensuisan Label Pelbagai Protokol telah dicadangkan sebagai rekabentuk rangkaian masa depan yang sangat praktikal dan mampu bertahan lama. Namun, memandangkan bidang ini masih baru, kajian terperinci berkaitan subjek ini masih belum diperolehi. Penyelesaian perebutan sumber telah banyak dikaji di dalam rangkaian Pensuisan Label Optik tanpa-sambungan namun peratusan ketibaan peket dalam susunan yang betul telah diketepikan sedangkan ianya adalah kayu ukur pencapaian yang penting untuk rangkaian sambungan-terbina. Di dalam kajian peringkat lapisan rangkaian projek ini, bafer optik menggunakan Talian Gentian Tertangguh (FDL) telah dibuktikan berkesan untuk menghalang keciciran peket tetapi kurang berkesan dalam memastikan ketibaan peket dalam susunan yang betul. Bafer Pelbagai-tingkat Talian Gentian Tertangguh Terkurang Panjang bersama dengan Penukaran Gelombangjarak telah dicadangkan dan dibuktikan sebagai teknik penyelesaian perebutan yang sangat praktikal yang menjamin ketinggian tahap ketibaan peket dalam susunan yang betul.

Satu lagi bidang penyelidikan yang penting ialah penciptaan teknik untuk melaksanakan pensuisan label pada setiap hentian di dalam rangkaian Pensuisan Label Optik. Di dalam kajian peringkat lapisan fizikal, teknik Lambda Selari telah diperkenalkan dan ditunjukkan sebagai cara yang mudah dan efektif untuk melaksanakan pensuisan label. Label pada kadar bit yang rendah dari beban-berbayar telah dijanakan dengan jarak beberapa nanometer di atas gelombangjarak yang dioperasikan oleh beban-berbayar tetapi masih didalam saluran Penggabungan Pembahagian Gelombangjarak yang sama. Label ini bergerak secara bersama dan selari dengan beban-berbayar disepanjang rangkaian dan melaksanakan pensuisan label di setiap hentian disamping masih mengekalkan tahap kuasa dan kadar kesilapan bit yang boleh diterima.

Sebagai kesimpulan, rangkaian Pensuisan Label Optik yang melaksanakan sistem Pensuisan Label Pelbagai Protokol boleh menawarkan penyelesaian yang lebih baik untuk merealisasikan rangkaian optik-sepenuhnya di masa depan. Disamping potensinya untuk menawarkan keberhasilan rangkaian yang tinggi melalui saiz-butiran pensuisannya yang terkecil, ia juga menawarkan kualiti pada penghasilannya dengan menjamin ketinggian tahap ketibaan peket dalam susunan yang betul. Akhir sekali dengan menggunakan teknik Lambda Selari di dalam pembinaan suis, mekanisma pensuisan label yang mudah dan efektif boleh direalisasikan.

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I certify that an Examination Committee met on 18th October 2002 to conduct the final examination of Rizaludin Kaspin on his Master of Science thesis entitled "Performance of Optical Label Switching Network with Multi Protocol Label Switching Implementation" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for the quotations and citation which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

RIZALUDIN KASPIN

Date:

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LIST OF ABBREVIATIONS

ASE	-	Amplifier Spontaneous Emission
BER	-	Bit Error Rate
BGP	-	Border Gateway Protocol
bps	-	bits per second
BPSK	-	Binary Phase Shift Keying
CR-LDP	-	Constraints Based Routing LDP
DLCI	-	Data Link Control Identifier
DWDM	-	Dense Wavelength Division Multiplexing
EDFA	-	Erbium–Doped Fiber Amplifier
FBG(s)	-	Fiber Bragg Grating(s)
FDL(s)	-	Fiber Delay Lines(s)
FEC	-	Forwarding Equivalence Class
GMPLS	-	Generalized Multi Protocol Label Switching
GVD	-	Group Velocity Dispersion
HOL	-	Head-Of-Line
IETF	-	Internet Engineering Task Force
IGP(s)	-	Interior Gateway Protocol(s)
IP	-	Internet Protocol
IS-IS	-	Intermediate System to Intermediate System
ISP(s)	-	Internet Service Provider(s)
KEOPS	-	KEys to Optical Packet Switching
LIB	-	Label Information Base
LDP	-	Label Distribution Protocol

LMP	-	Link Management Protocol
LSP(s)	-	Label Switched Path(s)
LSR(s)	-	Label Switched Router(s)
MPLS	-	Multi Protocol Label Switching
NCM	-	Network Control and Management
OBS	-	Optical Burst Switching
OCDM	-	Optical Code Division Multiplexing
OD	-	Origin-Destination
OLS	-	Optical Label Switching
OSPF	-	Open Shortest Path First
OXC	-	Optical Cross Connects
QoS	-	Quality of Service
RAM	-	Random Access Memory
RSVP	-	Resource Reservation Protocol
SCM	-	SubCarrier Multiplexing
SOA	-	Semiconductor Optical Amplifier
SONET	-	Synchronous Optical NETwork
TE	-	Traffic Engineering
TWC	-	Tunable Wavelength Converter
VCI	-	Virtual Channel Identifier
VPI	-	Virtual Path Identifier
WASPNET	-	WAvelength Switched Packet NETwork
WDM	-	Wavelength Division Multiplexing
XGM	-	Cross Gain Modulation
XPM	-	Cross Phase Modulation

CHAPTER 1

INTRODUCTION

This new millennium brings together tremendous development in one of the most preferable global data communications technology popularly known as Internet. Its widespread usage involving people from all walks of life has set a revolution in the way information is communicated. In the first part of this chapter, a brief introduction to the Internet is given. Next, issues related to the development in the Internet and optics technology are discussed. Eventually Optical Label Switching with MPLS implementations has been proposed as the future solution to those issues. This is followed by discussion on how the study carried out in this research project may provide insight on the viability of the proposed solution.

1.1 Characteristics of the Internet

The basic idea of the Internet is to support the transfer of packetized data traffic between computers and workstations connected together in an Internet Protocol (IP) network (Huitema, 2000; Uyless, 1999). This network employs Adaptive Routing features which means each packet traffic may take different routes through the network depending on network conditions at any particular time such as congestion or link failure. At the end of the message transfer the destination user may receive the packets out of order and not in sequence. Some packets experience little delay while others may take longer. The Internet operates as connectionless system, which means it does not maintain an ongoing knowledge of user's traffic and there is no fixed, predetermined switches path for packet to traverse from the origin to the destination host. The Internet offers best effort delivery services. If any problem occurs such as congestion or unavailable destination host, the traffic is discarded. The lost packets will be resent for another delivery attempt.

1.2 Development And Issues In The Internet And Optics Technology

In the following section, the issues related to Internet development and their subsequent repercussions to the optics technology are discussed.

1.2.1 Bandwidth Demand And WDM

One of the most notable trends of the Internet is its traffic growth. The expansions of IP network size as more computers are connected to the Internet and the emergence of new applications with higher bandwidth requirement contribute to the continuous traffic escalation. The traffic generated by the Internet has doubled every four to six months (Ramaswami, 2002). Internet call last about six times longer than a voice call. For the first time in history data traffic volume is bypassing voice traffic. This phenomenon led to the dramatic growth of bandwidth capacity of the transmission lines that connect each of the entity in the IP network.

Optical technology is undeniably the key enabling technology of the future transmission networks. Fiber optics for example, has revolutionized wired communication technology which used to depend largely on copper cables. Their ability to carry huge information capacity is their main advantage. This can be seen from Shannon-Hartley theorem which states that information carrying capacity is proportional to the channel bandwidth which in turns proportional to the frequency of the carrier. Since light is a carrier with the highest frequency among all the practical signals, it is therefore comprehensible why fiber optic communications system have the highest information carrying capacity today.

In this new millennium, the emergence of Wavelength Division Multiplexing (WDM) technology has revolutionized the carrying capacity of fiber optics. A single fiber which used to carry only one wavelength is now capable of carrying tens of different wavelengths in parallel. This is accomplished using a multiplexing technique that exploits the wavelength domain. Today, the advent of Dense Wavelength Division Multiplexing (DWDM) has further increased the number of wavelengths that can be multiplexed together in one fiber. Using channel spacing below 100 GHz, fiber optic communications system with 256 channels have been demonstrated (Mynbaev, 2001).

1.2.1.1 Backbone Capacity

Fiber optics is mainly deployed in the network backbone. The typical backbone links have evolved from DS-3 (45Mbps) to OC-12c (622 Mbps)(Collins, 1999). Bigger Internet Service Providers (ISPs) especially in the US have deployed many OC-48c links (2.5Gbps) as well as some OC-192c links (10Gbps). The trend now is rapidly moving into deployment of terabits per second backbone links. This is driven mainly by the growth in access lines capacity. The continuous demand for broadband access technologies such as Digital Subscriber Line and cable modem provide individual users with bandwidth of 1Mbps as compared to the maximum of 56 kbps over dial up lines while large corporations have embark on 155 Mbps leased lines in preference to 1.5 Mbps lines.

Besides that, another significant cause of bandwidth demand is the carrier's need to guarantee fail-safe networks. As telecommunications has become more critical to business and individuals, service providers have been required to ensure that their networks are fault tolerant and resistant to outages or otherwise they will be imposed with severe financial penalties should the outages occur. In order to meet these requirements they have broaden the route diversity either through ring configuration or 1+1 backup network provided on alternate fibers. Although 100% reliability could be achieved, this potentially doubles the bandwidth requirement.

1.2.1.2 All Optical Computer

In not so distance future the link's bandwidth capacity requirements will go beyond what we see today with the emergence of a new revolution in optics and computing technology, that is the advent of All-Optical Computer (Knier, 2000; Abdeldayem, 2000). This machine can operate much faster than the current electronics version. Computation and data transportation can be accomplished more rapidly with the speed of light as compared to the speed of electrons.

Hence, with optical computers to be used as clients and servers in the IP network we can imagine huge data per second will be generated and waited to be relayed to their respective destinations. This will definitely aggravates the issue of bandwidth capacity requirements.

1.2.2 End to end delay and All Optical Network

So much of the development in optical computers and the optic links that connect them, it would be worthless if the development in other IP network entities such as the nodes or routers that switch the traffic from one link to another does not keep in pace. As the network grows there is an increased demand on the routers to handle huge amount of routing information in addition to the applications data. End to end transmission delay will be very crucial in the network where huge data traffic will mostly dominate. Failure to keep up with the speed of the client and server demands will create bottleneck at the ingress, egress and transit nodes of the distributed network. To address this issue, researchers have come up with the concept of All-Optical Network to take advantage of processing signals at the speed of light. Today, the optical layer has been supplemented with more functionality, which were once in the higher layers. This helps to create the vision of All-Optical Network where all management is carried out in the optic layer. The optical network is proposed to provide end-to-end services completely in the optical domain, without having to convert the signal to the electrical domain during transit.

Today, most of optics-electronics-optics (O-E-O) conversion occurs in the transit nodes. The packet signal must be converted to electrical to facilitate switching process in link and network layers. This is so because optical signal processing as the most crucial technology in optical switching is still under research and yet to be fully developed.

Another factor that slows down the packet relaying process is the amount of transition the packet has to undergo during packet switching process at each node. Today's IP networks typically have four layers: IP for carrying applications, ATM for traffic engineering, SONET/SDH for transport, and DWDM for capacity. Besides slowing down the packet, this architecture also has been slow to scale, making it ineffective as the foundation for optical networks. Multi-layer architectures typically suffer from the lowest common denominator effect where any one layer can limit the scalability of the entire network.